DRAFT FINAL
EXPANDED ENGINEERING EVALUATION/COST ANALYSIS (EEE/CA)
FOR THE
McLAREN TAILINGS SITE
COOKE CITY, MONTANA

Engineering Services Agreement DEQ/MWCB 401027
Task Order Number 05

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APPENDIX G

ANNOTATED BIBLIOGRAPHY OF PREVIOUS RESEARCH ON METAL LOADING IN SODA BUTTE CREEK, MONTANA AND WYOMING

Annotated Bibliography

Anderson, J.R., 1995, Stream terraces of lower Soda Butte Creek, northeastern Yellowstone National Park: Middlebury, Vt., Middlebury College, unpublished Bachelor of Arts thesis, 35 p.

Badon, N.M., and Schrader, E.L., 1999, Preliminary geochemical study of Soda Butte Creek in Yellowstone National Park: Jackson, Miss., Journal of the Mississippi Academy of Sciences, v. 44, no. 1, p. 47-48.

Bureau of Reclamation, 1989, Analysis of corrective action alternatives for the McLaren tailings site, Cooke City, Montana: Billings, Mont., Bureau of Reclamation, Great Plains Region, 20 p.

Presentation of investigation results, data interpretation (site characterization) and analysis of corrective action alternatives for the McLaren tailings site near Cooke City, Montana. Report provides the technical basis for developing a full Engineering Evaluation/Cost Analysis (EE/CA) should the need for such a document be identified in the future. A number of alternatives were listed for dealing with four problems: runoff and seepage from the old mill and ore storage areas, flooding of Soda Butte Creek, tailings dam failure, and seepage from the tailings and tailings dam. No alternatives recommended.

_____1991, McLaren mine tailings, Soda Butte Creek - September 1990 water sample analysis review: Memorandum from J.R. Boehmke to D. Jewell, Billings, Mont., Bureau of Reclamation unpublished data.

A total of 22 samples were taken. Of 25 elements analyzed, 5 (Cd, Pb, Cu, Zn, and Fe) were chosen as elements that could potentially have an impact upon the aquatic life in Soda Butte Creek. One value exceeded the freshwater aquatic-life criterion for copper. In general, copper does not appear to be of concern to the aquatic environment in Soda Butte Creek, although certain conditions may initiate high concentrations. Iron concentrations were above the detection limit more often than other elements. It is the only element evaluated that consistently showed higher concentrations below the mine tailings, compared to the concentrations above the tailings. The iron concentration is high enough to cause iron precipitate to form on the stream substrate. This appears to have prevented the full utilization of the substrate by aquatic invertebrates, thereby reducing a major food source for the fish species inhabiting the reach of Soda Butte Creek below the tailings area.

Carolan, G. F., 1997a, Distribution and geochemistry of tailings contaminated floodplain sediments along Soda Butte Creek, Yellowstone National Park, Montana-Wyoming: Middlebury, Vt., Middlebury College, unpublished Bachelor of Arts thesis, 83 p.

_____1997b, Distribution and geochemistry of tailings contaminated floodplain sediments along Soda Butte Creek, Yellowstone National Park, Montana-Wyoming: The Green Mountain Geologist, v. 24, no. 2, spring 1997

The McLaren tailings impoundment is a significant source of acid drainage containing metals. Dissolved-copper concentrations in the water were highest during spring runoff. Floodplain tailings may be another significant source of trace-metal pollution.

Chadwick, J.W., 1974, The effects of iron on the macroinvertebrates of Soda Butte Creek: Bozeman, Mont., Montana State University, unpublished Master of Science thesis, 25 p., appendices.

Dissolved iron from the McLaren tailings is the primary water-quality problem affecting macroinvertebrates of Soda Butte Creek. Soda Butte Creek experiences substantial seasonal differences in discharge, which have been measured to be 20 times greater during spring runoff than in the fall.

Chaffee, M.A., Hoffman, J.D., and Tidball, R.R., 1995, Stream-sediment geochemistry in the Soda Butte Creek watershed in comparison to the surrounding region in Montana and Wyoming--Proceedings of the Second International Conference on Tailings and Mine Waste, Fort Collins, Colorado: Rotterdam, The Netherlands, Balkema Publishing,

Chaffee, M.A., 1998, Environmental geochemistry in Yellowstone National Park--Distinguishing natural and anthropogenic anomalies: Yellowstone Science, Agenda and Abstracts, 125th anniversary symposium, v. 6, no. 2, p. 29.

Clancy, C., Bureau of Reclamation, written commun., 1988: Billings, Montana, Personal communication with J. Boehmke, Montana Department of Fish, Wildlife, and Parks, Bureau of Reclamation.

Personnel from the Montana Department of Fish, Wildlife, and Parks electrofished Soda Butte Creek in October 1985. Two stations were shocked, one 500 feet upstream from the mouth of Sheep Creek and the other a 400-foot stretch near Silver Gate. The Sheep Creek station yielded 26 cutthroat ranging from 7.6 to 11.6 inches in length, and averaging about 1/3 pound. The Silver Gate station yielded 18 cutthroat trout ranging from 6.1 to 10.1 inches in length, and averaging about 1/4 pound.

Davenport, P., 1972, Iron and the pollution problem in Yellowstone National Park.

David Stiller and Associates, 1983, Determination of public health hazards associated with the McLaren tailings pond near Cooke City, Montana: Helena, Mont., David Stiller and Associates, 32 p.

At the request of the Abandoned Mine Reclamation Bureau, Montana Department of State Lands, a study was conducted to ascertain the possibility of contamination of domestic water supplies near Cooke City, Montana. The majority of Cooke City residents obtain their water from a spring-fed holding tank above the valley 1/8 mile northwest of town. Soda Butte Creek loses a large quantity of its flow to the McLaren tailings throughout the year. Because of this, it is anticipated that the Soda Butte Creek alluvial aquifer downgradient from this site may be impacted by highly mineralized ground water emanating from the shallow McLaren tailings aquifer. The extent and magnitude of this contamination is unknown. No significant contamination of domestic water resources was identified during this investigation, other than elevated iron concentrations in surface water samples obtained from Woody Creek and Soda Butte Creek below the tailings.

Decker-Hess, J., and White, R.G., 1987, In-stream flow requirements of Soda Butte Creek, Yellowstone National Park: Bozeman, Mont., Montana Cooperative Fish Research Unit, Montana State University, 30 p.

Instream flow requirements were determined for Soda Butte Creek, Yellowstone National Park using the Montana Department of Fish, Wildlife and Parks wetted perimeter/inflection-point method. Previous data collected on the physical description of the creek, its water quality, macroinvertebrate and fisheries populations and other data were summarized. Management recommendations based on literature review and current conditions were formulated. Instream flow requirements for upper Soda Butte Creek were a minimum flow of 13 cfs and an optimum flow of 24 cfs, and for lower Soda Butte Creek, 46 cfs minimum and 58 cfs optimum. Based on an evaluation of fishery data, recreational use, current condition and other resource information, a minimum flow of 20 cfs and an optimum flow of 58 cfs were recommended for Soda Butte Creek at the Northeast Entrance and the Lamar River Trail bridge.

Duff, D.A., 1972, Reconnaissance survey of aquatic habitat conditions affected by acid mine pollution in the Cooke City area, Custer and Gallatin National Forests, Montana, and Shoshone National Forest, Wyoming: U.S. Fish and Wildlife Service, Division of Range and Wildlife, Northern Region, 18 p.

Runoff and seepage from the McLaren tailings to Soda Butte Creek are adversely impacting the creek ecosystem. No fish are present in Soda Butte Creek below the tailings site for 3 miles.

Ecology and Environment, Inc., 1987, McLaren mill tailings endangerment review, Cooke City, Montana: Denver, Colo., Ecology and Environment, Inc. Technical Directive Document F08-8612-03, draft report, 30 p.

There is a concern that valley residents are consuming water from domestic wells completed in alluvial deposits downgradient of the tailings pile. A health threat may exist and needs to be explicitly determined. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) environmental threats may be present and affect riparian wetlands and aquatic life. The tailings qualify for evaluation as a Special Studies Waste under the Superfund Amendments and Reauthorization Act (SARA) and a site investigation (SI) is warranted. An SI would include drilling of monitor wells in alluvial aquifer upgradient and downgradient of tailings, tailings sampling to determine metals concentrations and hazardous waste quantity under definition of special-study wastes, sediment sampling and benthic studies of Soda Butte Creek to evaluate contaminant migration and environmental impact, and surface-water sampling to document a contaminant release.

_____1988, Preliminary endangerment assessment for McLaren mine tailings, Cooke City, Montana: Denver, Colo., Ecology and Environment, Inc. Technical Directive Document T08-8705-016.

Surface-water quality samples analyzed showed only iron concentrations are occurring at levels that are toxic to aquatic life (1,020 µg/L at station MCSW-5 and 2,850 µg/L at station MCSW-6).

Elliott, J.E., Kirk, A.R., and Johnson, T.J., 1979, Field guide--Gold-copper-silver deposits of the New World District: Crown Butte Mines, Inc., unpublished report, 19 p.

Environmental Response Team, 1988, McLaren tailings--Evaluation of four alternatives for a removal action: Edison, N.J., Environmental Response Team Technical Directive Document T08-8802-024, variable pagination.

Release of heavy-metal laden leachates from the McLaren mill site has been well documented. Their transport off-site and into nearby Soda Butte Creek is clearly evident by the pronounced discoloring of the streambed. Environmental samples have quantified this contamination (Ecology and Environment, Inc., 1988). The instability of the tailings has been evaluated and confirmed (Maddox, 1983). The failure of the tailings under Probable Maximum Flood conditions has been predicted (Womack, 1984). Tailings failure would also induce a secondary, less direct, adverse effect upon the local economies of Cooke City and Silver Gate. These local economies rely heavily on tourism generated by the ideal environment of YNP. For the above reasons, it is concluded that the risks posed to the environment and public welfare by the McLaren tailings site justify a Removal Action. The feasibility of four removal action alternatives is examined.

Epstein, J.L., 1997, Hydraulic aspects of the McLaren Mine tailings dam-break flood in Soda Butte Creek, Yellowstone National Park: Middlebury, Vt., Middlebury College, unpublished Bachelor of Arts thesis, 74 p.

In June 1950 the McLaren impoundment failed, flushing pyritic tailings down the Soda Butte floodplain. The tailings were deposited as overbank sediments with thickness up to at least 60 cm. The tailings contain high concentrations of heavy metals such as copper and lead, which now impact the river ecosystem. This study was conducted to evaluate the hydraulic aspects of the tailings flood.

Epstein, J.L., and Meyer, G.A., 1997, Hydraulic aspects of the McLaren Mine tailings dam-break flood in Soda Butte Creek, Yellowstone National Park (abs.): Geological Society of America, Abstracts with Programs, v. 29, no. 1, p. 43.

Erickson, B.M., and Norton, D.R., 1994, Monitoring of Soda Butte Creek riparian zone, *in* Proceedings of the American Water Resources Association, June 26-29, 1994, Jackson Hole, Wyoming, [abs.]: Bethesda, Md., American Water Resources Association.

Riparian vegetation (grass, horsetail, and willow) showed greater concentrations of copper, lead, and zinc immediately downstream of the tailings than upstream, with concentrations decreasing downstream towards the Park boundary.

Ewing, R., 1991, 1992, 1993, 1994, Riparian landform and deposit mapping, Soda Butte Creek, northeast Yellowstone National Park: Mammoth, Wyo., National Park Service, Yellowstone National Park Division of Research, Investigator's annual reports, accessed November 25, 1999, at URL http://165.83.23.11/amoeba/resiar.nsf.

Objective: Project will map fluvial deposits and landforms in the riparian and near-riparian areas of Soda Butte Creek in northeast Yellowstone National Park and the adjacent Gallatin National Forest. Information on fluvial deposits and landforms on the major Willow Study plots will be gathered to determine preferred substrates and landforms for Yellowstone National Park willow species. Deposit/landform maps will be made of the riparian zones for further riparian plant and ecological studies. Study will use black-and-white, color, and color infrared aerial photography supplemented by extensive soil coring to map Soda Butte Creek.

1991 Findings and status: None.

1992-94 Findings and status: None. Project incomplete. Investigator's term of employment ended, no further funding available.

Ewing, T.T., 1997a, Particle size variations and metals in flood-deposited mine tailings along Soda Butte Creek, Yellowstone National Park: Middlebury, Vt., Middlebury College, unpublished Bachelor of Arts thesis, 103 p.

_____1997b, Particle size variations and metals in flood-deposited mine tailings along Soda Butte Creek, Yellowstone National Park: Green Mountain Geologist, v. 24, no. 2, p. 13.

Defines the stratigraphy of the deposits and variations in particle size with depth, examines changes in particle size of tailings deposits with distance of transport, and examines relation of texture to metals concentrations.

Forstner, U., and Wittman, G.T.W., 1983, Metal pollution in the aquatic environment: Berlin, Springer-Verlag, 486 p.

Although all metals found in water or sediment from Soda Butte Creek can be toxic, copper has been shown to be the most toxic to aquatic life.

Glidden, R., 1982, Exploring the Yellowstone high country, a history of the Cooke City area, 2d ed.: Cooke City, Mont., Cooke City Store, 120 p.

Since the 1860s, prospectors have been seeking minable quantities of metals in south-central Montana. In the vicinity of Soda Butte Creek, multiple gold, silver, and copper deposits were discovered and several mines and smelters were developed. The area became known as the New World or Cooke City Mining District. The McLaren mine produced 2,000 short tons (1,814 metric tons) of copper and 60,000 troy ounces (1,866 kg) of gold between 1933 and 1940.

Green, J.A., written commun., 1972, Personal correspondence from Region VIII Administrator: Denver, Colo., U.S. Environmental Protection Agency.

In 1969, Soda Butte Creek was rerouted around the north edge of the impoundment. The tailings were leveled, graded, covered with a 0.5-1.5 meter thickness of alluvial sand and gravel, and seeded with grass.

Green, V.A., U.S. Environmental Protection Agency, written commun., 1972, Memorandum to Donald G. Willems regarding Yellowstone National Park, Baseline water quality report: Kansas City, Mo., U.S. Environmental Protection Agency, Region VII, 30 p.

Copper and zinc concentrations in Soda Butte Creek could reach undesirable levels and be a detriment to aquatic life.

Hill, R.D., 1970, McLaren mine tailings mine drainage: Federal Water Quality Administration, Robert A. Taft Water Research Center, unpublished report, 12 p.

The McLaren mine and mill are located east of Cooke City, Montana, adjacent to Soda Butte Creek. The mine was established in 1933 and operated until January 1953. At one time it was the largest operating gold mine in Montana. Some copper and silver were also mined. A large tailings area was developed next to the mill. Serious erosion of the tailings began about 1957, the sediment washing into Soda Butte Creek. The cyanide process was used in the mill. Prior surveys have shown that the fish production of Soda Butte Creek is poor. Causes of this condition have been suggested as: (1) sediment on stream bed, (2) toxic material from the tailings area, and (3) iron precipitates on streambed. The streambed of Soda Butte Creek from just below the tailings area to the entrance of Yellowstone National Park, some 4 1/2 miles, has the typical "rusty" colored iron precipitate.

The McLaren mine tailings area is responsible for a decrease in pH and alkalinity and an increase in conductivity, hardness, SO_4, Fe, Mn, Zn, and Cu concentrations.

_____1977, Mine drainage control from metal mines in a subalpine environment - a feasibility study: Cincinnati, Ohio, U.S. Environmental Protection Agency report EPA 600/2-77-224, 149 p.

The mill area is underlain by moraine deposits of Pleistocene age covered with a thin veneer of recent stream deposits. 14.5 meters of gravel below the tailings and above bedrock were encountered in one drill hole. The thickness of the gravel at this location places serious engineering constraints upon any attempts to flood the tailings pond or to dam the tailings and gravel, preventing ground water within the tailings from passing through the gravel. Tailings consist of phyllosilicates (clays), tectosilicates (predominantly feldspars and quartz), sulfides (mostly pyrite), iron oxides (magnetite, geothite, and ferric hydroxide), and calcium salts (gypsum and calcite). Investigated several remediation options including removing the tailings, treating the effluent from the tailings pile, and infiltration control by resealing the dam on the lower end of the tailings pile.

Holmes, M.A.; 1995, Treatability study, McLaren tailings site, Cooke City, Montana: U.S. Environmental Protection Agency Contract No. 68-C4-0022, Final report.

INTERA, Inc., 1991, McLaren tailings site, Soda Butte Creek water quality analysis: Salt Lake City, Utah, INTERA Inc., 7 p., appendices.

McLaren tailings site is under a two-part EPA administrative order for corrective action. First action–dam stabilization–was completed by Kennecott in September 1990. Second action–dewatering of the tailings–has been ordered to be completed by October 31, 1991. It appears that in the past, discharges of tailings material entered the creek, resulting in precipitation of iron material to the stream bottom. This quite insoluble material coated the stream gravels and filled the spaces between rocks, rendering the stream bottom inhospitable to organisms and spawning fish. Therefore, a section of Soda Butte Creek below the tailings became unsuitable for trout habitat. Since then the causes of these discharges have been corrected and the water quality has improved. Iron precipitate remains on the stream rocks below the tailings because it is very insoluble and has yet to be washed away. This will occur naturally, however, and the stream will continue to return to natural trout stream conditions whether the tailings are dewatered or not. From a stream quality perspective, therefore, there is no reason to undertake a disruptive and costly dewatering project at the McLaren tailings site.

Johnson, T.W., 1994, Au-Cu-Ag skarn and replacement mineralization in the McLaren deposit, New World District, Park County, Montana: Economic Geology, v. 89, no 54, p. 969-993.

Elevated levels of trace metals in stream sediments can originate from a number of sources, including highly mineralized Eocene volcanics and Cambrian sediments above Cooke City.

Keigley, R.B., 1993, Distribution and population dynamics of exotic plants on the Soda Butte floodplain: Mammoth Hot Springs, Wyo., National Biological Service Greater Yellowstone Field Station, Investigator's annual report, accessed November 21, 1999 at URL http://165.83.23.11/amoeba/resiar.nsf.

Objective: To determine the effect of different forms of vegetation on the sediment deposited during annual flooding.

Findings: During the 1993 field season, the author found evidence that the depositional environment of Soda Butte Creek may have changed in the recent past. Specifically, there is lichenometric evidence of a 50-centimeter drop in flood stage that may have been caused by either entrenchment or by an increase in width-to-depth ratio. A preliminary survey suggests that there has been a change in the texture of sediment recently deposited during flood events. If further study supports these observations, these changes in fluvial processes have major ecologic implications.

_____1994. Relationships between fluvial landforms and riparian vegetation in the Soda Butte drainage.

Kennecott Corporation. 1990. Workplan for remediation of the McLaren tailings site. Cooke City, Montana: Kennecott Corporation.

The McLaren tailings site has been designated an emergency response action site by EPA region VIII. Kennecott Corporation was named a potentially responsible party (PRP). Kennecott reviewed the corrective action plan and elected to manage and perform the corrective actions at the site in lieu of the Bureau of Reclamation. Kennecott retained the geotechnical firm of Sergent, Hauskins, and Beckwith (SHB) to conduct an independent stability analysis of the McLaren tailings dam. SHB concluded that the dam is stable, both statically and dynamically, with an adequate factor of safety, and therefore further stability work on the dam is not warranted. Runoff is to be collected and diverted around the tailings in a diversion channel constructed immediately upslope of the tailings. Kennecott and its contractors believe a portion of the high iron content in the water below the dam is a result of water coming into contact with the relatively small amount of tailings deposited below the tailings dam. Kennecott plans to make a best-effort attempt to excavate the bulk of the tailings deposited below the dam and deposit them in the tailings area behind the dam.

Kerr, M., written commun., 1986, Soda Butte Creek survey: November 13, 1986 office memorandum to the Montana State Department of Health and Environmental Sciences, 12 p.

The channel bottom was "cemented" for about 1.6 km downstream of the tailings in a reach where only a few small trout were evident.

Knudson. K., and Estes, C., 1975, Biological study, acid-mine control feasibility study, Cooke City, Montana: Montana Department of Fish and Game report, May-October, 1975, 33 p.

In 1969, Soda Butte Creek was rerouted around the north edge of the impoundment. The tailings were leveled, graded, covered with a 0.5-1.5 meter thickness of alluvial sand and gravel, and seeded with grass.

Ladd, S.C., 1995, Channel morphology controls on the spatial distribution of trace metals in bed sediments in Soda Butte Creek, Montana: Bozeman, Mont., Montana State University, unpublished Master of Science thesis, 83 p.

Consistent and statistically significant changes in copper concentrations occur at the scale of the individual morphological units.

Ladd, S.C., Marcus, W.A., and Cherry, S., 1997, Trace mineral segregation within morphological units in Soda Butte Creek: Environmental Geology and Water Sciences, v. 36, no. 3, p. 195-206.

Landis, J.D., and Meyer, G.A., 1997, Recent debris-flow and flash-flood history of northeastern Yellowstone National Park: Green Mountain Geologist, v. 24, no. 2. p. 15-16.

Lynn, S.V., U.S. Geological Survey, written commun., 1998: Helena, Mont., U.S. Geological Survey memorandum.

The 1996 peak discharge of about 2,450 ft3/s deposited overbank sediments up to a few decimeters below the highest tailings deposits.

Maddox, G.E., 1983, Evaluation of stability of tailings dam and peak flow for channel design, McLaren mill tailings project. Cooke City, Montana: Spokane, Wash., George Maddox and Associates, Inc., 20 p.

Stability of the McLaren Mine tailings was investigated. The 50-year flood was estimated to be 1,226 cubic feet per second (cfs), and the 100-year flood to be 1,665 cfs. Four of five failure surfaces analyzed had a safety factor of less than one. Determined that dam failure is "imminent."

Mahoney, Dan, 1992, 1993, 1994, 1995, 1996, Effects of acidic mine waters on the aquatic invertebrates community of Soda Butte Creek: Mammoth, Wyo., National Park Service, Yellowstone National Park Fisheries Program, Investigator's annual reports, accessed November 26, 1999 at URL http://165.83.23.11/amoeba/resiar.nsf.

Objective [1992]: To monitor the water quality of a 7-kilometer stretch of Soda Butte Creek immediately upstream from the northeast entrance of Yellowstone National Park which has been polluted from acid mine drainage waters from the tailings heap of the abandoned McLaren gold mine near Cooke City, Montana.

Objective [1993-96]: To assist the National Park Service in the interpretation of data on macroinvertebrates and fishes in Soda Butte Creek, a stream affected by acidic mine waters from the tailings of the abandoned McLaren gold mine, Cooke City, MT.

1992-93 Findings and Status: Pollution effects are severe immediately downstream of the tailings, but stream conditions improve gradually in a downstream direction.

1994-96 Findings and Status: Pollution effects, though severe immediately downstream from the tailings, have been reduced in recent years as the result of efforts to better contain the tailings and prevent seepage of acidic waters.

Mangum, F.A., 1984, Aquatic ecosystem inventory macroinvertebrate analysis: U.S. Department of Agriculture-Forest Service, Intermountain Region Aquatic Ecosystem Analysis Laboratory, Brigham Young University, Provo, Utah, Annual progress report.

_____1986, Aquatic ecosystem inventory macroinvertebrate analysis: U.S. Department of Agriculture-Forest Service, Intermountain Region Aquatic Ecosystem Analysis Laboratory, Brigham Young University, Provo, Utah, Annual progress report, 6 p.

Biological indices of macroinvertebrate community health in Soda Butte Creek downstream from the tailings were lower than those of similar streams in this region between 1984 and 1986 and, "there appeared to be stress conditions [to macroinvertebrates] at each of the sampling stations," including one located about 1.6 kilometers within Yellowstone National Park.

_____1987, Aquatic ecosystem inventory macroinvertebrate analysis: U.S. Department of Agriculture-Forest Service, Intermountain Region Aquatic Ecosystem Analysis Laboratory, Brigham Young University, Provo, Utah, Annual progress report.

_____1991, 1992, 1993a, 1994, Aquatic ecosystem analysis for Soda Butte Creek (macroinvertebrate and water quality): Mammoth Hot Springs, Wyo. U.S. Fish and Wildlife Service, Yellowstone National Park, Annual progress report, accessed November 26, 1999 at URL http://165.83.23.11/amoeba/resiar.nsf.

Objective: To monitor pollution from the McLaren Mine tailings in Cooke City.

1991-94 Findings and status: None.

_____1993b, Aquatic ecosystem inventory, macroinvertebrate analysis: U.S. Department of Agriculture-Forest Service, Intermountain Region Aquatic Ecosystem Analysis Laboratory, Brigham Young University, Provo, Utah, Annual progress reports, 1991-1992.

Results from another study with data from sampling stations located immediately upstream from the boundary of YNP indicated that there could be effects from both mine tailings and tributary stream waters, since many of the tributaries drain old abandoned mines.

Macroinvertebrate indices improve downstream of the Park boundary, but there appears to be some opportunity for management to improve water quality and instream habitat quality.

Marcus, W.A., 1995, Research on trace metal concentrations in sediments and their impacts in Soda Butte Creek, Montana and Wyoming: Interagency meeting on Soda Butte Creek watershed, Mammoth, Wyo., Monograph.

_____1997, Morphologic controls on multiscale distributions of mining-derived trace metals in riparian sediments, resultant biotic impacts, and implications for monitoring and remediation: Bozeman, Mont., 18th annual meeting, Society of Wetland Sciences, Monograph.

Metals vary between riffles, pools, bars, and glides. Macroinvertebrate populations generally increase in number and diversity with increasing distance downstream from Cooke City. The primary control on metal concentrations and variability in upper reaches of the stream appears to be related to oxide coatings on the sediment.

Marcus, W.A., and Ladd, S.C., 1995, Reach scale spatial variability of trace metal concentrations in channel bed sediments, Soda Butte Creek, Montana: Bozeman, Mont., Geological Society of American, Rocky Mountain section, Monograph.

Marcus, A.D. Ladd, S.C., and Crotteau, M., 1996, Channel morphology and copper concentrations in stream bed sediments, *in* Nelson, J.D., and others, eds., Proceedings of the Third International Conference on Tailings and Mine Waste, Fort Collins, Colorado., USA: Rotterdam, The Netherlands, Balkema Publishing, p. 421-430.

Metals are segregated into discrete subpopulations within morphologic units such as riffles, pools, and glides. Sediment metal concentrations decreased with distance from the tailings in high gradient riffles and glides but in some backwater pool sediment, copper was higher far downstream of the tailings than immediately below them. Some of the highest concentrations of copper were inside the park boundary. Typically, the silt-clay fractions contained the most copper but the coarser 1-2 millimeter fraction often contained the next highest concentrations.

Marcus, W.A., Stoughton, J.A., Ladd, S.C., and Richards, D., 1995, Trace metal concentrations in sediments and their ecological impacts in Soda Butte Creek, Montana and Wyoming, *in* Meyer, Grant, ed., Late-Pleistocene-Holocene evolution of the northeastern Yellowstone landscape: Middlebury Vt., Middlebury College, Friends of the Pleistocene - Rocky Mountain Cell 1995 field conference guidebook, 9 p.

Research by author began in 1993, focusing on characterizing the range of spatial and temporal variability in trace-metal concentrations in active channel sediments, explaining the processes controlling that variability, and documenting the impacts (if any) of trace-metal concentrations on biotic populations.

Trace metal concentrations in the stream bed generally decrease downstream as a function of dilution mixing with clean sediments from tributaries. Local scale metal variations in riffles, pools, and bars vary as a function of sediment size and perhaps as a function of residence time and resultant accumulation of iron oxides. Biodiversity within the stream improves downstream, but has shown little improvement over the last 50 years. In contrast, some biotic impacts in the floodplain 20 kilometers downstream are as severe as those at the tailings site. The amount of impacted area in the floodplain, however, is slowly improving over time as contaminated sediments are removed by floods.

_____1998, Geomorphic controls on long-term biotic response to sediment contamination from mining in the stream and floodplain zones of Soda Butte Creek (abs.): Yellowstone Science, v. 6, no. 2, 39 p.

Marcus, W.A., Meyers, G.A., and Nimmo, D.R., 2001, Geomorphic control of persistent mine impacts in a Yellowstone Park stream and implications for the recovery of fluvial systems: Geology, v. 29, no. 4, p. 355-358.

A half-century after mine closure, metal contamination from sulfide ore mining in the headwaters continues to impair riparian vegetation and aquatic macroinvertebrates along Soda Butte Creek, Yellowstone National Park. A tailings dam failure in 1950 emplaced metal-rich sediment at high floodplain levels, above 50 yr to 100 yr flood stages in 1996 and 1997. These large natural floods removed only a small part of the contaminated sediment through bank erosion; they also failed to lower in-channel copper concentrations, because increased erosion of mine waste during high flows balances increased inputs of uncontaminated sediments, generating no net change in concentrations. Geomorphic processes controlling movement of contaminated sediments indicate that mine impacts will persist for centuries in Soda Butte Creek and imply long-lasting impacts in similarly affected streams worldwide.

Maxim Technologies, 1999, New World Mining District response and restoration project: Accessed November 11, 1999 at URL http://www.maximtechnologies.com.newworld/.

This web site has been provided by the Gallatin National Forest to disseminate information, reports, and data for the New World Mining District response and restoration project. It includes such features as project status, schedule, description, background, contacts, and other general information. From this site you will be able to access project reports, documents, maps and key data sets. All relevant reports prepared through the duration of this project will be posted to the site.

Merritt, R.W., and Cummins, K.W., 1996, An introduction to the aquatic insects of North America, 3rd ed.: Dubuque, Iowa, Kendall Hunt Publishers, 862 p.

In the fall of 1995, replicate samples of macroinvertebrates at each site were collected to assess metal uptake and to analyze community structure.

Metesh, John, English, Alan, Lonn, Jeff, Kendy, Eloise, and Parrett, Charles, 1999, Hydrogeology of the upper Soda Butte Creek basin, Montana: Billings, Mont., Montana Bureau of Mines and Geology, 66 p., 1 sheet.

Compilation of existing hydrogeological data. Evaluation of ground-water and water-quality relationships with respect to ground-water development in the area.

Meyer, G.A., 1992, Mine tailings sediment contamination in the Soda Butte Creek drainage, Montana and Wyoming: Final report, 16.8-25-92.

_____1993, A polluted flash flood and its consequences: Yellowstone Science, v. 3, no. 1, p. 2-6.

According to National Park Service records, the McLaren tailings impoundment failed in June 1950, spilling a large amount of tailings into the creek. Deposits of the tailings have been found over 15.5 miles downstream, just above the confluence of Soda Butte Creek and the Lamar River.

_____1995, Tailings impoundment failure and floodplain sediment contamination along Soda Butte Creek, Yellowstone National Park, Montana-Wyoming (abs.): Geological Society of America, Abstracts with Programs, v. 27, no. 4, 47 p.

_____1997, Stream ecosystems and geoscience in northeastern Yellowstone National Park (abs): Geological Society of America, Abstracts with Programs, v. 29, no. 6, p. 66.

Meyer, G.A., and Bingham, M.K., 1995, Soda Butte Creek floodplain tailings deposits and McLaren dam-break flood, *in* Meyer, G.A., ed., Late-Pleistocene-Holocene evolution of the northeast Yellowstone landscape: Middlebury, Vt., Middlebury College, Guidebook, Friends of the Pleistocene Rocky Mountain Cell, p. 13-14.

Meyer, G.A., and Watt, P.M., 1998, Mine tailings contamination of floodplain sediments in Yellowstone National Park: National Geographic Society grant #5699-96.

Metals-laden mine waste contaminated the Soda Butte Creek floodplain in Yellowstone National Park when a tailings dam failed in 1950, producing a major flood. A large volume (approximately equal to $3.1x10^4$ *cubic meters) of contaminated sediments was deposited along the 30-km floodplain.*

Miller, W.R., Meier, A.L., and Briggs, P.H., 1997, Geochemical processes and baselines for stream waters for Soda Butte-Lamar Basin and Firehole-Gibbon Basin: U.S. Geological Survey Open-File Report 97-550, 27 p.

There is minimal to no effect on the chemistry of Soda Butte Creek from the presence of mine workings or tailings above Cooke City for this time of year (Fall 1996).

Nimmo, D.R., Willox, M.J., LaFrancois, T.D., Chapman, P.L., Brinkman, S.F., and Greene, J.C., 1998, Effects of metal mining and milling on boundary waters of Yellowstone National Park, USA: Environmental Management, v. 22, no. 6, p. 913-926.

Aquatic resources in Soda Butte Creek within Yellowstone National Park, USA, continue to be threatened by heavy metals from historical mining and milling activities that occurred upstream of the park's boundary. This includes the residue of gold, silver, and copper ore mining and processing in the early 1900s near Cooke City, Montana, just downstream of the creek's headwaters. Toxicity tests, using surrogate test species, and analyses of metals in water, sediments, and macroinvertebrate tissue were conducted from 1993 to 1995. Chronic toxicity to test species was greater in the spring than the fall and metal concentrations were elevated in the spring with copper exceeding water quality criteria in 1995. Tests with amphipods using pore water and whole sediment from the creek and copper concentrations in the tissue of macroinvertebrates and fish also suggest that copper is the metal of concern in the watershed. In order to understand current conditions in Soda Butte Creek, heavy metals, especially copper, must be considered important factors in the aquatic and riparian ecosystems within and along the creek extending into Yellowstone National Park.

Norton, D.A., 1993, 1994a, 1995a, 1996a, 1997a, Monitoring of Soda Butte Creek riparian zone: Denver, Colo., U.S. Geological Survey Branch of Geochemistry, Investigator's annual reports, accessed November 26, 1999 at URL http://165.83.23.11/amoeba/resiar.nsf,

Objective [1993, 1994, 1995, 1997 reports]: Establish present-day trace-element concentrations in vegetation, soils, water, and stream sediments of the Soda Butte Creek riparian zone to assess the impact of past mining operations (McLaren Mine) and to monitor the proposed Noranda (Canadian owned) gold, copper, and silver mine to be located 2 miles outside the Park boundary.

Objective [1996 report]: Establish present day trace element concentrations in vegetation, soils, water, and stream sediments of the Soda Butte Creek riparian zone to assess the impact of past mining operations (McLaren Mine) and to provide a chemical baseline for these operations and for the exploratory operations of the Noranda (Canadian owned) gold, copper, and silver mine located 2 miles outside the Park boundary. The baseline is being established in the event that the property trade fails to remove the mining operation. If the trade of lands is successful it will still be necessary to proceed with the study for the clean-up of the historic mine activities on the mountain and of the McLaren tailings and waste ore deposits near Cooke City.

1993, 1994, 1995 Findings and status: Representative vegetation species, stream sediments, and water were collected along the Soda Butte Creek riparian zone, Yellowstone National Park, during a reconnaissance field trip in the fall of 1992. Seven sampling sites were established downstream from the old McLaren Mine tailings site. The McLaren Mine tailings contain elevated concentrations of arsenic, copper, iron, lead, and zinc. Preliminary vegetation results indicate that the highest concentrations of copper, lead, and zinc occur at the tailings sites and decrease downstream in samples of grass, horsetail, and willow. Results for the other species do not reflect this decrease. [1994, 1995]: Iron concentrations in all species sampled do not appear to decrease downstream.

M.A. Chaffee plans to present his findings for a regional geochemical database to the geographic information system for the Greater Yellowstone Area ecosystem at the next annual physical science symposium. We will also present a heavy-metals investigations program sponsored by the Gallatin National Forest where part of it focuses on the Noranda Mine sites.

1996 Findings and status: Monitoring of the Soda Butte Creek watershed has been in progress since 1992, and has been continued to date sampling plant species, soils, water, and stream sediments. Results from the vegetation samples suggest willow and grass will serve as biomonitors. Chemical analysis for plant species has been held up due to lack of funding. Results of water samples taken this past field season have been received by William Miller, and will be reported at the next interagency meeting to be held in the Park during September 1997. These include chemical analysis for cations and anions, pH, conductivity, and alkalinity. Maurice Chaffee will be reporting on our results for stream sediments collected by our team of Survey geologists in September 1996. I have completed a series of pH, conductivity, and temperature measurements of water samples taken in the field and will be reporting on filtration rates and microscopy of precipitate from these samples. At the meeting I will also present my findings on sieve testing of stream sediments and microscopy of the separated fractions with information on their carbonate and iron contents. I plan to organize and moderate the Fourth Interagency Conference on the Soda Butte Creek Watershed to be held in Mammoth in September 1997.

1997 Findings and status: Results on this project were presented at the Forth Interagency Conference held in September, which I organized and moderated. Monitoring of the Soda Butte Creek riparian zone continues to be taking place by a number of agencies presenting papers at the symposium. We have recommended that the gaging station at the park entry on Soda Butte Creek be upgraded for continuous monitoring of the discharge. Our findings on the geochemical sampling and chemical analysis are being accumulated into reports by Maurice Chaffee and associates.

_____1994b, Monitoring of Soda Butte Creek riparian zone (abs. and poster): Proceedings of the American Water Resources Association symposium, Effects of Human-Induced Changes on Hydrologic Systems, Jackson Hole, Wyo., Abstracts and Posters.

_____1995b, Monitoring of Soda Butte Creek riparian zone, (abs. and poster): Proceedings of the American Water Resources Association symposium, Abstracts and Posters.

_____1996b, Monitoring of Soda Butte Creek Riparian Zone, *in* Nelson, J.D., and others, eds., Proceedings of the Third Interagency Conference on Tailings and Mine Waste, Fort Collins, Colorado: Rotterdam, The Netherlands, Balkema Publishing.

A study of cation and anion concentrations in water, and heavy-metal concentrations.

_____1996c, Metal uptake of plants along the Soda Butte Creek watershed in Montana and Wyoming, 1992-1994 (abs. and poster): Second Interagency Conference on Soda Butte Creek Watershed, Yellowstone National Park.

_____1996d, Study of cation and anion concentrations in water, and heavy metal concentrations in stream sediments, along the Soda Butte Creek watershed in Montana and Wyoming, 1992-1994 (abs. and poster): Second Interagency Conference on Soda Butte Creek Watershed, Yellowstone National Park.

_____1997b, Monitoring of Soda Butte Creek Riparian Zone, *in* Nelson, J.D., and others, eds., Proceedings of the Third Interagency Conference on Tailings and Mine Waste, Fort Collins, Colorado: Rotterdam, The Netherlands, Balkema Publishing.

Establish present-day trace-element concentrations in vegetation, soils, water, and stream sediments of the Soda Butte Creek riparian zone to assess the impact of past mining operations (McLaren Mine) and to monitor the proposed Noranda (Canadian owned) gold, copper, and silver mine to be located two miles outside the Park boundary.

_____1997c, Environmental geochemical baseline studies in the Yellowstone National Park area: Proceedings of the Greater Yellowstone Ecosystem Science Conference, Yellowstone National Park.

_____1997d, Dispersion of selected elements in stream sediment samples collected between Cooke City, Montana and the confluence of the Lamar and Yellowstone Rivers: Proceedings of the Third Interagency Conference on Soda Butte Creek Watershed, Yellowstone National Park.

Obermann, W.R., 1998, Estimates of volume and mass for flood-deposited mine tailings along Soda Butte Creek, Yellowstone National Park: Middlebury, Vt., Middlebury College, unpublished Bachelor of Arts thesis, 60 p.

Omang, R.J., U.S. Geological Survey, written commun., 1988, Flood peak and flood routing determinations for Soda Butte Creek: Helena, Mont., Memorandum.

Flood studies conducted by the USGS using channel geometry techniques indicate that for Soda Butte Creek above the Miller Creek confluence the 50-year design flood is 1,040 cubic feet per second (cfs), and the 100-year design flood is 1,430 cubic cfs. Below Miller Creek, the 50-year design flood discharge is 1,200 cfs, and the 100-year design flood discharge is 1,620 cfs. Approximately 700 cfs of the 100-year flood would discharge across the tailings pond. These data clearly indicate the substantial flooding potential which exists at the site.

Omang, R.J., Parrett, Charles, and Hull, J.A., 1983, Flood estimates for ungaged streams in Glacier and Yellowstone National Parks, Montana: U.S. Geological Survey Water-Resources Investigations Report 83-4147, 10 p.

Pickett, F.J., and Chadwick, J.W., 1972, Studies on Soda Butte, Slough, and Iron Springs Creeks, Yellowstone National Park: Bozeman, Mont., Montana State University, Final report for contract 2-101-0387, 54 p.

Seepage from the mill tailings at Cooke City is adversely affecting the water quality of Soda Butte Creek. The natural flora and fauna present above the tailings were either eliminated or severely reduced immediately below the tailings.

Richards, D.C., Marcus, W.A., Nimmo, D.R., 1997, Persistent impacts of mining on macroinvertebrates in Soda Butte Creek: North American Benthological Society.

Satchell, B., 1995, A new battle over Yellowstone Park: U.S. News and World Report, March 13, 1995.

Shands, Tom, 1998,'Smoking gun' - Researchers link old mine tailings to riparian damage: Yellowstone Ecosystem Studies, accessed December 20,1999 at URL http://fp2.in-tch.com/www.yellowstone.org/p_sodabutte.htm.

"Our research very clearly shows the impacts of past tailings releases," Dr. Andrew Marcus said, adding the extent of the damage to the Soda Butte drainage extends well within Yellowstone Park. Marcus said that within the grasslands community in the floodplain of Soda Butte, there was decreased biodiversity and decreased biomass. Researchers also compared the macroinvertebrate population of Soda Butte Creek below the McLaren tailings to that of Pebble Creek, which is entirely within the Park, has never been mined, and flows into Soda Butte Creek. In Pebble Creek researchers found 19 different types or organisms. In Soda Butte Creek below the tailings, they only found six types of organisms.

In addition to the plants and insects,,, he (Marcus) said researchers have also found evidence of "bioaccumulation" in fish, particularly the liver and muscle tissue.

Sharpe, F.P., and Arnold, B.B., 1966, Summary report, 1965: Yellowstone National Park, Wyo., Fishery Management Program, Lake and Stream Surveys, 59 p.

Focused on certain streams in the northeast section of the Park. General stream survey intended to classify waters and locate possible problem areas.

Shuler, S., U.S. Forest Service, written commun., 1994: Gardiner, Mont., U.S. Forest Service, Gallatin National Forest, Gardiner Ranger District, unpublished data, 45 p.

In 1993, only two trout were found within 300 meters downstream of the McLaren tailings impoundment.

Sonderegger, J.L., 1976, Hydrologic and geochemical controls on tailings pond drainage affecting Soda Butte Creek, Cooke City, Montana (abs.): Geological Society of America, Abstracts with Programs, v. 8, no. 5, p. 634.

Sonderegger, J.L., Wallace, J.J., Jr., and Higgins, G.L., Jr., 1976, Acid mine drainage control – feasibility study, Cooke City, Montana: Butte, Mont., Montana Bureau of Mines and Geology Open-File Report 23, 197 p.

Stoughton, Julie, 1995, The impacts of trace metals on grass communities along the floodplain of Soda Butte Creek: Bozeman, Mont., Montana State University, unpublished Master of Science thesis, 109 p.

Results indicated that the density, diversity and biomass of vegetation decreased at threshold concentrations for metals and pH at 4 meadow sites along Soda Butte Creek. Plant diversity in relation to metals showed a decrease.

Terrasi, J.D., written commun., 1995, Unpublished report on analysis of Soda Butte Creek water and sediments.

U.S. Environmental Protection Agency, 1971a, Baseline water quality survey: Kansas City, Mo., U.S. Environmental Protection Agency, Region VII.

In the vicinity of the McLaren mine tailings on Soda Butte Creek outside of the Park boundary, there is a decrease in the types and numbers of bottom organisms.

_____1971b, Baseline water quality survey report – Yellowstone National Park: Kansas City, Mo., U.S. Environmental Protection Agency, Region VII, 133 p.

_____1972, Yellowstone National Park baseline water quality survey: Denver, Colo., U.S. Environmental Protection Agency, Region VIII report for May – September, 1970, 194 p.

In the vicinity of Cooke City, Montana, a decrease of numbers and types of bottom organisms in Soda Butte Creek indicated marginal water quality.

_____1987, Impact assessment - McLaren mine tailings pile, Cooke City, Montana: Edison, N.J., U.S. Environmental Protection Agency.

Invertebrate densities and diversities decrease immediately below the tailings site and then tend to recover further downstream.

_____1989, Request for removal action approval at the McLaren tailings site, Cooke City, Montana: Action memorandum NPL Site ID #93, 7 p.

A buttress berm was installed by U.S. Environmental Protection Agency and Kennecott to reinforce the tailings dam and some of the tailings below the dam were removed.

U.S. Fish and Wildlife Service, 1977, Fishery and aquatic management program in Yellowstone National Park: Billings, Mont., U.S. Fish and Wildlife Service, Fisheries Resources Technical report for calendar year 1976, 81 p.

While angler use and success were average when compared to other Park fisheries, historical descriptions of Soda Butte Creek suggest fishing is much below its potential. Correction of the stream's pollution problems is needed for any significant improvement in the sport-fishery.

_____1979, Fishery and aquatic management program in Yellowstone National: Billings, Montana., U.S. Fish and Wildlife Service, Fisheries Resources Park Technical report for calendar year 1978, 43 p.

In the late 1800s, Soda Butte Creek had a reputation for "fast fishing and large trout," but by 1931 the fishery was reported as only "fair to poor." Although angler success is presently only slightly above average by Park standards, fishing quality has improved since 1974 despite increasing use, which is unusual. This may indicate that the extensive rehabilitation work done on the McLaren tailings in the late 1960's has had a positive effect on the fish population. Alternatively, it may suggest that there is a population interaction with the Lamar River which has been catch-and-release only fishing for six years and has built up a robust population.

_____1981, Fishery and aquatic management program in Yellowstone National Park: Billings, Mont., U.S. Fish and Wildlife Service, Fisheries Resources Park Technical report for calendar year 1980, 23 p.

Declines in the Soda Butte fishery have been compounded by pollution from mine tailings at an abandoned mine site in Cooke City, Montana. Angler use on this stream was high in the early 1970's, fell in 1974-75, and has increased since that time. Measures of success continue to be above average for Park waters; however, these rates are believed to be artificially supported by population interaction with the Lamar River which has a documented increase in robustness since catch-and-release regulations were implemented in 1974.

Terrasi, J.D., written commun., 1995, Unpublished report on analysis of Soda Butte Creek water and sediments.

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______1985, Fishery and aquatic management program in Yellowstone National Park: Billings, Mont., U.S. Fish and Wildlife Service, Fisheries Resources Park Technical report for calendar year 1984.

Soda Butte Creek contains the ninth most popular stream fishery in YNP. Approximately 80 percent of the fish landed in Soda Butte Creek are released. A decrease in angler use has been the most obvious change in the Soda Butte fishery since it was last surveyed in 1981. An increase in fish numbers in the upper section signifies improving conditions for the trout population.

______1992, 1993: Recovery of a cutthroat trout population in a 5-kilometer reach of Soda Butte Creek: Mammoth, Wyo., U.S. Fish and Wildlife Service, Yellowstone National Park, Investigator's annual reports, accessed November 24,1999 at URL http://165.83.23.11/amoeba/resiar.nsf,

Objective: To monitor the recovery of the cutthroat trout population affected by the fish toxin rotenone during fish management activities in 1988.

1992, 1993 Findings and status: Abundance, community length structure, and age distribution are similar to pretreatment levels, indicating recovery of population.

Varley, John, 1992, 1993, 1994, Soda Butte Creek mine tailings analysis: Mammoth, Wyo., National Park Service, Yellowstone National Park Center for Resources, Investigator's annual reports, accessed November 24,1999 at URL http://165.83.23.11/amoeba/resiar.nsf,

Objective: In 1991, sediments were discovered along the entire length of Soda Butte Creek that have been identified as tailings from the McLaren tailings site above Cooke City. Toxicity and heavy metals analysis will be performed to determine the impact of these tailings on the ecology of the area.

1992-94 Findings and status: None.

Weight, Willis, 1998, Groundwater-flow assessment of the upper Soda Butte Creek drainage basin, Park County, Montana and Wyoming: Butte, Mont., University of Montana, Investigator's annual report, accessed November 24,1999 at URL http://165.83.23.11/amoeba/resiar.nsf,

Objective: To understand the basic hydrogeology of the upper Soda Butte drainage from Silver Gate to Cooke City. Characterization will be performed through performing pumping tests, static water-level surveys, and stream gaging. Additional analysis of the role of bedrock is to be explored. The data will be integrated into a groundwater flow model.

Findings and Status: Three aquifer tests were performed and water level surveys were conducted in the summer and fall of 1997 and throughout the fall of 1998. Stream gaging was performed. A groundwater flow model using a graphical interface GMS was used to create a three layer model of the area. This was put together as part of a MS thesis by Amy Huskey. She defended her thesis is 1998, but corrections are still underway. Alan English is continuing a thesis study in the Silver Gate area, including water-quality data.

Womack, Ray, geological consultant, written commun., 1984, Probable maximum flood and failure hazard, McLaren mill tailings, Cooke City, Montana: Billings, Mont.

Probable maximum flood is approximately 14,000 cubic feet per second (cfs), but would likely range from 11,000 to 18,000 cfs. In the event of a probable maximum flood the McLaren tailings impoundment is likely to fail, releasing large amounts of tailings downstream.

[illegible]t, A., 1998, The use of multispectral digital imager to map hydrogeomorphic stream units in Soda Butte and Cache Creeks, Montana and Wyoming: Bozeman, Mont., Montana State University, unpublished Master of Science thesis, 76 p.